FIELD EVALUATIONS OF AN ARSENIC REDUCTION SYSTEM IN THE CHELMSFORD AREA

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Ontario
Ministry of the Environment

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OF AN
ARSENIC REDUCTION SYSTEM IN THE CHELMSFORD AREA
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Ministry of the Environment,
Northeastern Region,
Sudbury, Ontario.

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SUMMARY

Upon discovering higher than normal levels of arsenic in a number of private individual wells in the Chelmsford area, correction by way of an experimental method of individual water treatment was investigated by the Sudbury District Abatement office of the Ministry of the Environment.

The method of treatment investigated is one developed by the Nova Scotia Research Foundation Corporation to correct an arsenic problem with groundwater in an area near Dartmouth, Nova Scotia. The method relies on oxidation by chlorination and subsequent exchange of arsenic from the water by an iron hydroxide -impregnated filter media.

Evaluation of the system included the installation and operation of two units in 3 locations; two private homes and the MTC patrol garage in the Chelmsford area.

The system proved to be effective at consistently reducing arsenic to levels below the Provincial Rejection Criterion but treatment may have to be limited to drinking/cooking water only in order to make operation economically feasible. The operation of units proved to be very reliable with average 'down time' being only 3.5% of the total test period.

Poor initial water quality of the three water supplies and the need for chlorination as part of the arsenic removal process caused some aesthetic problems with the finished water quality. The incorporation of an iron removal unit and a recommended method of operation is proposed to alleviate these problems.

Arsenic reduction system capital costs and operating costs were computed during the evaluation and estimates for 1982 were determined to be $1,795. and $275. per year respectively.

Recommendations towards the acceptance, effectiveness, service and maintenance, follow-up sampling programs, and the system's eligibility for the Low-Cost Alternative or Small Systems Alternative Grant program are proposed.

RECOMMENDATIONS

1. The Nova Scotia Research Foundation Corporation system of arsenic reduction should be considered as an effective method for the treatment of non-serviced individual water supplies with arsenic concentrations greater than 25 µg/L.

2. The arsenic reduction filters should be installed to treat only water to be used for drinking and cooking in order that only annual filter media replacement is necessary. Connection of the arsenic filter unit to the kitchen cold water tap or to a separate potable water tap is recommended.

3. Arsenic reduction units should be serviced annually to replace filter media and to clean and maintain equipment to ensure a safety margin for the production of potable water.

4. Homeowners should follow maintenance procedures outlined in the report.

5. The Ministry of the Environment should accept properly prepared treated water samples brought in by homeowners with arsenic reduction systems for arsenic analysis at the MOE laboratory. The recommended sampling frequency is weekly for the first month of operation and quarterly thereafter for as long as practicable.

6. Where the operation of an arsenic reduction system creates aesthetic problems with the water supply due to water discolourations and iron precipitation, iron removal devices should be installed.

7. Use of the N.S.R.F.C. arsenic reduction system should be considered as an eligible alternative for the implementation of corrections to elevated arsenic problems of average arsenic greater than 25 µg/L as part of a Ministry of the Environment Low-Cost or Small Systems Alternative Grant Program.

INTRODUCTION AND BACKGROUND

The Ontario Ministry of the Environment has been investigating the occurrence of higher than normal levels of arsenic in private domestic wells of the Chelmsford area, 15 km West of Sudbury in Northern Ontario (see Figure 1).

The problem was first discovered in 1978-79 during a Province-wide groundwater investigation of well water contamination associated with road salt storage piles. Results from this survey indicated that a well located at the Ministry of Transportation and Communications Patrol Yard in Chelmsford had unusually high levels of arsenic (results exceeded the Ministry's Objective Criterion for Drinking Water).

In 1979, a survey of area domestic wells was implemented to confirm the arsenic levels previously found, and to determine how widespread the occurrence prevailed and what levels of arsenic were involved. A report was released on this sampling program (MOE, April 1980). Over 130 well water supplies were sampled for arsenic in the general area between Azilda and Dowling.

The survey and the accompanying research towards the cause of this anomoly determined at the time that, four wells had

arsenic concentrations in excess of the Ministry's Rejection Criterion (50 µg/L or 50 ppb)* and twelve wells contained arsenic concentrations between the Ministry's criteria of 10 µg/L (Objective) and 50 µg/L (Rejection).

The source of contamination was determined to be the natural leaching of arsenic from arsenical-bearing bedrock formations found in the area. (MOE, July 1980).

Since the discovery of higher than background arsenic levels in some well waters in the Chelmsford area, the local Ministry office had taken the very conservative position of recommending that water not be consumed where arsenic levels exceeded 10 µg/L, the MOE Objective Criterion. At that time, very little information was available to confirm that arsenic concentrations would not seasonally fluctuate above the Provincial Rejection Criterion of 50 µg/L.

Since the beginning of the study (MOE April, 1980), over 500 well water samples have been analyzed for arsenic, providing a sound basis to predict seasonal fluctuations. An evaluation of these data undertaken during the final stages of this arsenic reduction study indicated that water supplies having an arsenic concentration of 25 µg/L or less were highly unlikely to ever exceed the 50 µg/L Rejection limit. Due to the fluctuations in arsenic concentrations found in the Northeastern Region, it is presently

*1 microgram per litre (µg/L) = 1 part per billion (ppb).

recommended that water supplies confirmed to have arsenic concentrations greater than 25 µg/L be considered to have a probability for exeeding the Rejection Criterion.

An extensive review of literature on the toxicity of arsenic supported the position that water is safe to drink unless it regularly exceeds a level of 50 µg/L arsenic. Long term consumption of water with 50 µg/L of arsenic or greater, may impact on one's health.

In light of this evaluation and review, the initial very conservative position has now been modified. Private water supplies found to have arsenic concentrations of less than or equal to 25 µg/L, are considered by the Northeastern Region of the Ministry to be safe for human consumption. Water supplies with greater than 25 µg/L arsenic should be treated to reduce arsenic levels or an alternative supply should be used.

Since the present arsenic reduction system study was initiated on the limited 1980 data base and the recommendations of that report (MOE, April, 1980), correction was attempted on supplies having arsenic concentrations which are now accepted as safe for human consumption (i.e. <25 µg/L). The initial report, (MOE, April, 1980) discussed a number of alternatives for correction of water supplies which contained arsenic in excess of 5 µg/L. They were as follows:

(a) Haulage of potable water;

(b) Providing new or sharing existing good quality wells low in arsenic;

(c) Extending the watermain from Chelmsford to the area;

(d) A combination of (a) and (c);

(e) Individual water treatment systems.

Since that report, the following further developments have occurred:

Alternative (a), haulage of potable water, has been followed by most residents but has not been considered to be the final solution.

Alternative (b), developing new wells, has been investigated, but that evaluation (MOE, July, 1980) indicated that only random success in finding supplies low in arsenic immediately adjacent to those high in arsenic could be anticipated. Sharing of existing low arsenic wells is available, but only to a few situations. Hence, the Ministry determined that other alternatives must be more fully investigated.

Alternative (c), extending the watermain, remains available to solve some cases but may not be cost-effective and is not feasible to solve the more isolated problems.

For alternative (d), the combination of new wells and extending the watermain, comments remain as stated for Alternatives (a) and (c).

This report discusses the investigation conducted by the Ministry of the Environment into the viability of one option available within Alternative (e), individual water treatment systems.

Four individual water treatment systems were considered in the previous MOE report (MOE, April 1980):

(a) Reverse Osmosis;
(b) Lime Precipitation;
(c) Carbon Filtration;
(d) Anionic Exchange.

In each instance, backwashing of the units at prescribed intervals and disposal of water was necessary to assure adequate long-term performance. This procedure would produce a very highly arsenic-contaminated wastewater. Disposal of this waste on site is undesirable as it could more seriously contaminate the groundwater of the area. Haulage of the waste water was considered unworkable.

Thus, for these reasons and because frequent maintenance and inspection was required, the previously mentioned units were not more fully investigated.

Shortly following that report, a more promising process became known and was chosen to be tested in the Chelmsford area. This method involves an ion exchange process only recently developed by the Nova Scotia Research Foundation Corporation (N.S.R.F.C.) of Dartmouth, Nova Scotia (G. Lutwick, 1979).

Faced with elevated arsenic levels in private domestic wells of homes near Dartmouth, Nova Scotia, the N.S.R.F.C. tested this process in treatment units installed in over 20 homes with arsenic problems substantially more acute than in the Chelmsford area. These field trials determined that the units were operating efficiently and provided a potable source of water with few maintenance problems. The attraction of the N.S.R.F.C. arsenic reduction process was that the products of the reaction were an insoluable precipitate and the creation of water. This precipitate and the arsenic reduction media can safely be disposed of at any local landfill site once it reaches the end of its effective lifetime.

It is the purpose of this report to detail the evaluation of treatment capabilities of the N.S.R.F.C. system. It is also to make recommendations towards its potential use as a viable alternative for the correction of high arsenic levels in the Chelmsford area and other sites in Ontario that may experience this problem.

Investigation of this option began in late August of 1980. The N.S.R.F.C. was contacted and arrangements made to inspect their treatment units in operation and discuss the process with its inventor, Dr. G. D. Lutwick. As a result of that visit, filter media for the N.S.R.F.C. process was donated by the N.S.R.F.C. to construct two treatment units for field performance trials.

Agreement for the field trials in Chelmsford and funding arrangements were confirmed in September, equipment suppliers researched, and purchase and installation quotations solicited in October, and installation of two units achieved in November of 1980. The two arsenic removal units were operated at three different locations; two private homes and on two separate occasions at the Ministry of Transportation and Communications patrol garage in Chelmsford.

In the evaluation of this equipment, this report deals with four main areas:

1. Assessment of treatment efficiencies at:
   (a) Arsenic concentrations below 25 µg/L;
   (b) Elevated arsenic concentrations;
   (c) High and low water consumption rates.

2. Optimization of efficiency by chemical additions.

3. Confirmation of operating efficiencies over long-term usage on private groundwater systems of the Chelmsford area;

4. Development of operating and maintenance requirements.

5. Development of capital and operating costs.

Interim reports on this study have been made public by way of letters and presentations to the Town of Rayside-Balfour Council in February and June of 1981, with this being the final report.

THEORY OF OPERATION

The following is an abbreviated discussion of the chemical theory of operation for the Nova Scotia Research Foundation Corporation's arsenic reduction system taken from reports published by that organization (G. Lutwick, 1979) and is provided in order that the process may be more fully understood.

In general, arsenic is known to occur in well waters as a mixture of two separate oxidation states, Arsenic (III) (As (III)) and/or Arsenic (V) (As (V)).

The trivalent arsenic species, As (III), is most commonly present as a compound of arsenic, oxygen and hydrogen known as arsenious acid and its dissociation components (listed below):

arsenious acid	H_3AsO_3
arsenite species	$H_2AsO_3^-$
	$HAsO_3^=$
	$AsO_3^{\equiv}$

Arsenious acid tends to be less reactive and forms few arsenite salts when it is present with other chemicals under normal well water conditions.

The pentavalent species, As (V), when present in well water, most commonly occurs as arsenic acid and its dissociation components, called arsenates, (listed below):

arsenic acid	H_3AsO_4
arsenate species	$H_2AsO_4^-$
	$HAsO_4^=$
	$AsO_4^{\equiv}$

When present in association with other chemicals, and specific chemical conditions, these species may combine to form many different compounds, some of which are insoluble precipitates, that is a solid. It is this particular

property of arsenic acid and arsenates, the formation of insoluble precipitates, which allows the N.S.R.F.C. arsenic reduction process to be successful in removing arsenic from water.

The N.S.R.F.C. arsenic reduction unit is essentially a filter bed of inert material (diatomecious earth) impregnated with iron hydroxide ($Fe(OH)_3$). As pentavalent arsenic-bearing waters pass through this filter, a chemical exchange takes place, whereby the iron of the iron hydroxide in the media reacts with the arsenates to form a chemically inert compound, iron arsenate ($FeAsO_4$). Water is also formed in this reaction which is indicated below:

$$Fe(OH)_3 + H_3AsO_4 \rightarrow FeAsO_4 + 3H_2O$$

Effective completion of the above reaction depends upon:

a) Arsenic being present in the As (V) state
and

b) the pH of the solution being within the range of 4 to 8.

In order to accomplish arsenic removal, the mixture of As(III) and As(V) in the groundwater is subjected to the addition of chlorine bleach (sodium hypochlorite) to oxidize all arsenic components to As(V). As previously stated, the N.S.R.F.C. reduction process removes only As(V).

EXPERIMENTAL DESIGN

In order to satisfy the original objectives of this study, it was necessary to install arsenic reduction units at three separate locations. A unit was installed at two homes on Joanette Road and on two separate occasions at the M.T.C. garage, all locations being just west of Chelmsford. The following listing indicates how each of the study objectives was addressed:

1) The units were installed to treat all household waters for the total test period of 5 to 8 months in order to provide evaluation of operation efficiencies.

2) (a) Home #1 and the M.T.C. garage served as sites of evaluation of the treatment efficiencies where arsenic concentrations exceeded the Objective Criterion only (10 µg/L).

   (b) Home #2 provided a site where arsenic levels greatly exceeded the Ministry Rejection Criterion (50 µg/L).

   (c) The M.T.C. garage further served as a site for assessment of treatment efficiencies under continuous flow conditions.

3) The effects of chemical additions on the efficiency of arsenic reduction were tested at Home #1.

4) Experience at each test site aided in the development of proper operating procedures.

5) All three sites served to provide background for the development of capital and operating cost estimates.

MATERIALS AND METHODS

A schematic diagram of an arsenic reduction unit and its relationship to a typical household distribution system, as installed for the purpose of this study, is depicted in Figure 2. Appendix I lists the various components and their specifications as used in this experiment. Table 1 indicates dates of receipt of filter media from Nova Scotia and dates of installation and final samplings.

All components, except the iron hydroxide-impregnated filter media, were available from commercial water treatment suppliers. The filter media itself was obtained directly from the N.S.R.F.C. at no charge to the Ministry in order to allow its evaluation. The complete system can easily be installed in less than a day by any competent plumber using ordinary copper plumbing fixtures.

The arsenic reduction unit operated in the distribution line under normal operating pressure conditions. It was located after the pressure tank such that any possible damaging surges of water pressure, due to pump operations, would be eliminated.

A chemical feed pump was installed to inject hypochlorite solution into the water line after the well pump and prior to the pressure tank. This chemical feed pump was installed to operate only when the well pump was activated. This location was chosen to permit completion of mixing to take place in the pressure tank. For the purpose of the pH control experiment, an additional feed pump and solution tank was also installed in a similar location to operate with the well pump.

The arsenic reduction unit consisted of a 25 x 122 cm fiberglass cylinder with 48 cm of media. Flow through the unit was via the downflow mode with the outlet from the base of the unit. A pressure release valve was installed on the upstream connection to prevent the possible buildup of air pressure in the filter unit.

The flow pattern through the filter media column assured ample contact time to allow completion of the chemical reaction. No mechanical components were involved which might involve frequent maintenance.

Next in line was a particle filter which reduced the possibility of particulates contaminating the household water. Finally, a water meter was installed to provide an accurate record of the amount of water treated by the unit. Several manual valves were installed to allow bypassing of the unit when servicing or removal became necessary.

A 'brown water' problem resulted from the oxidation of iron by hypochlorite injected as part of the arsenic reduction system. In an effort to remove iron prior to oxidation, a water softener was located upstream of the site of hypochlorite injection.

The unit used for iron removal was an ion exchange type using sodium zeolite media. It was set up to automatically backwash 3 times a week. Backwash water was discharged to the basement sump for eventual pump-out to the side-yard by the sump pump. Special controls were set up so that the hypochlorinator was not operating while the well pump was supplying backwash water upstream of the hypochlorite injection site.

Samples of untreated and treated water were taken on average 3 times per week for arsenic analysis. Samples were taken only after allowing the pump to run for 1½ minutes in order to assure the sampling of freshly treated water. Samples were taken directly from the pump for raw water and normally

at the kitchen sink for treated water. Analysis of other routine parameters associated with drinking water was done less frequently. All samples were sent to the Ministry of the Environment laboratories in Toronto for analysis (MOE 1981). On each sampling occasion, water meter readings were recorded and field chlorine residual tests of treated waters were performed. Any physical observations of water quality and comments from the occupants were also noted.

Results of analysis were received two to four weeks after taking the sample. This produced some limitations in recognizing loss or changes in treatment and in determining whether modifications in operation resulted in improvements. Analysis results, together with chlorine residuals, meter readings, sampling dates and operational notes were important in evaluating system performance.

When pH adjustment experiments were in progress, field pH readings were taken and the dosing rates were adjusted as necessary. pH reducing compounds used for this study were reagent grade sodium bisulphate initially, and for later trials, sulphuric acid mixed with raw water. Concentrations and dosing rates were previously determined by lab titration and knowledge of flow rates of the chemical pump and the home water system.

RESULTS AND DISCUSSION

The intensive sampling program carried out for the purpose of this study has resulted in one of the more comprehensive data accumulations of the water quality and water usage of private individual water systems ever undertaken in the Province. The two arsenic exchange units were studied for a combined period of over 1.5 years. During that period, in excess of 400 samples were analyzed for arsenic while another 100 samples were analyzed for up to 15 additional water quality parameters.

Raw Water

A summary of general water quality results of raw water and treated water samples is provided in Table 2. In general, well water at all three sites could be considered as moderately hard (200 mg/L $CaCO_3$) and slightly alkaline (pH = 7.5 to 8.0).

At Home #1, the Objective Citeria of three water quality parameters were continously exceeded. Iron, manganese and turbidity were found at levels normally considered objectionable. Iron varied from a low of 0.03 mg/L to a high of 3.1 mg/L. Manganese was continuously high and normally in the 0.23 to 0.49 mg/L range. Consequently, the

turbidity and colour of these waters were also variable and sometimes objectionable. On several occasions, the raw and treated waters had a yellow tinge and water turbidity ranged from 2.4 to 46 Formazin Turbidity Units (F.T.U.). On several occasions, hydrogen sulphide odour was detected by the sampler.

At Home #2, iron varied considerably as well, ranging from 0.66 to 3.55 mg/L. In general, water was less turbid than at Home #1 (.11 to 10.0 FTU) but often exceeded MOE's Objective Criterion. The only sample analyzed for manganese showed a rather high level of 0.20 mg/L.

The M.T.C. patrol garage water quality was in many respects superior to the other two study sites. However, it too was higher than objectives for turbidity, iron and manganese but in each case, only very slightly. Variations of all three parameters were not as extreme as found in the two homes on Joanette Road.

Arsenic values in the raw water at all 3 sites were found to fluctuate over a surprisingly wide range. Considerable variation could be expected for arsenic values from one day to the next.

At Home #1, arsenic values ranged between <1 and 28 µg/L with an average value of 14.8 µg/L.

At Home #2, arsenic values ranged between 50 and 280 µg/L with an average of 136.4 µg/L.

At the M.T.C. patrol yard garage during the first trial period, arsenic levels ranged from 4 to 26 µg/L with an average of 15.6 µg/L. During the second run, arsenic levels were in the lower range initially, but subsequently increased with continued 24 hour flow conditions. By the end of the test period, arsenic levels ranged from 14 to 38 µg/L with an average of 25.0 µg/L.

This phenomenon of increasing arsenic concentrations with continued use was also noted in newly drilled wells by G. D. Lutwick (personal communication) in the Nova Scotia arsenic studies.

Treated Water

Results indicate that arsenic reduction systems did not significantly alter the concentrations of most parameters other than arsenic. The media did, however, filter out a significant amount of iron, and particulates as reflected by turbidity and shown in Table 2.

The results for iron, if prorated for the total period of operation at Home #2, for example, show that the arsenic unit filtered out a total of some 60g of iron from the raw water. However, short term occurrences of iron precipitate "brown water" clouds were noted by water users.

Home #2 chloride levels in treated waters were slightly more elevated than raw waters (by 10 mg/L). Since ferric chloride is used in preparation of the media, increases in chloride levels might be attributed to this. This minor addition of chlorides, however, did not affect the potability of the water.

During chlorination of the supply, chlorine residuals were maintained relatively high for most of the testing period. Because of the varying water quality, it was felt that a residual of 0.5 to 1.0 mg/L may be necessary to ensure the oxidation of Arsenic (III) to the Arsenic (V) state. This feature of high chlorine did, however, prove to be aesthetically unacceptable to the residents because of the odour. This aesthetic problem can be overcome by reduction of the level of chlorination and by the installation of a carbon filter system.

Arsenic Exhange Efficiencies

The efficiencies of the reduction units in removing arsenic are summarized in Table 3. On average, the units exchange from 25 to 77% of the total arsenic present in solution. The highest rate of removal (77%) was found at Home #2 which had the highest strength arsenic (average 136 µg/L).

(a) Low Arsenic Levels

At Home #1 and for the first run at the M.T.C. garage, arsenic in raw water averaged near 15 µg/L. These sites were used to test the units on low arsenic level sources. The units in place at these locations treated in excess of 80 m^3* of water at Home #1 and 100 m^3 at the MTC garage. For those trials, a total of 33 m^3 and 36 m^3 of finished water was produced at Home #1 and the M.T.C. garage respectively with arsenic levels below the Provincial Objective of 10 µg/L. Individual incidents in excess of 10 µg/L in the treated water did occur infrequently during that period at Home # 1 (see Figures 3 and 4).

Our study showed that an average of 0.42 m^3 (90 Imp. gal.) of water per day was used at Home #1 and 0.45 m^3/day (100 Imp. gal. per day) at Home #2. Although water usage by households on municipal water systems can be greater than 0.75 m^3/capita/day (165 Imp. gal./cap./day), private well supplies, particularly in the Chelmsford area, cannot usually provide as large a daily quantity as consumed by municipal water users. In view of the water usage experience in the study, and allowing some latitude, a figure of 0.5 m^3/day (110 Imp. gal./day) was adopted for purposes of water use calculations for households served by private wells.

*1 m^3 = 1 cubic metre = 220.4 Imperial Gallons.

The unit at Home #1 provided water with arsenic levels below the Objective Criterion of 10 µg/L for a period of ~70 days. If this unit were installed to service only water for drinking and cooking purposes, a much longer lifetime of operation with finished water having an average arsenic concentration below the Objective Criterion of 10 µg/L could be assumed.

A figure of 0.05 m^3 (10 imp. gal.) of water per day has been suggested as an estimate of a household's actual drinking and cooking water consumption (Lutwick 1979). If only this water were treated, the filter media of the unit in Home #1 could have provided ~650 days of drinking and cooking water at an arsenic concentration averaging below the Objective Criterion.

Table 4 summarizes similar prorated filter media lifetimes for each test site if set up to treat for total water usage and alternatively, if only for potable water usage. Prorated lifetimes were assumed from calculated time periods based on 0.05 m^3/household/day and the experienced throughput volumes of water quality meeting the Provincial Objective Criterion of 10 µg/L and the Rejection Criterion of 50 µg/L.

In the case of Home #1, the raw water arsenic never exceeded the Rejection Criterion. Hence, the determination of a prorated life for treatment meeting this criterion is not applicable.

As can be seen in Figure 3, the unit at Home #1 provided the most sporadic treatment. On 12 separate occasions in the seven months of operation, levels of arsenic in treated water exceeded those of raw well water. Some of these occasions were also accompanied by the presence of H_2S in raw water and a yellow colouration in the treated waters.

Other water quality characteristics of Home #1 which could affect arsenic reduction performance are the excessive levels of iron (1.8 mg/L average) and particulates as measured by turbidity (20 FTU average).

Table 2 summarizes data for this site and gives an indication of the very poor general water quality conditions which the arsenic reduction unit was subjected to.

Also a potential factor for the erratic efficiency was the fact that the arsenic reduction filter bed material installed in the unit at Home #1 was approximately 2½ months old when installed (see Table 1). It is

possible that the extended length of time that the filter media was not used, could have caused a substantial reduction in its efficiency. During tests in Nova Scotia, the media for one of the tests was allowed to stand for one year prior to installation. When installed, a marked decrease in the effective lifetime of the units was determined (Lutwick 1979). So, the arsenic removal ability of the filter media can be affected by the length of shelf time prior to installation. This problem was later attended to by storage of new filter material in containers of water as recommended by Lutwick (1979).

In the final analysis, the average level of arsenic in the raw water at Home #1 is relatively low (14.6 µg/L). The arsenic reduction system lowered the raw water arsenic to a level below the Provincial Objective Criterion for the initial 33.2m^3 of water processed. However, the treatment of water after this throughput volume, while still generally being reduced in arsenic concentration, developed a marked inconsistency ranging above and below the Objective Criterion level.

Hence, for this low level arsenic source (arsenic in the raw water is less than the Rejection Criterion), provision of a treatment benefit of lowering arsenic below the Objective Criterion would require frequent filter media changes to treat all household water. Limiting treatment to drinking and cooking water would be required to reduce filter replacement to once per year.

The other water source with lower level arsenic (less than the Rejection Criterion of 50 µg/L), the MTC garage, where arsenic removal was investigated, was marked consistently with less fluctuation in arsenic reduction efficiency over considerable throughput volume compared to Home #1.

During the first run, the unit was subjected to the routine water usage habits of the garage (approximately 0.5 m^3/day). An average removal efficiency of 50% was provided over the first 38 m^3 processed, providing water quality below the Objective Criterion of 10 µg/L arsenic. After 38 m^3, removal efficiencies flucutated between 10 and 35% until at 75 m^3 of treatment throughput, it became very sporadic with discontinuous treatment. Thus, treatment efficiency for removal of arsenic from this low level source decreased substantially from initial demonstrated values with extended usage.

On the second run, the arsenic reduction unit, with a fresh replacement of filter media, was subjected to a continuous (24 hour) flow of approximately 10 times the previous daily consumption of 0.5 m^3/day. The purpose of this run was to confirm whether treatment to the Objective Criterion (10 µg/L) would be achieved to the previously demonstrated volume of run #1 in the short period of time remaining in the study.

As with the first run, initial finished water met the Objective Criterion of 10 µg/L. However, at the higher flow rate, arsenic removal efficiency decreased to a relatively consistent 31% average for a throughput of 55 m^3. Increasingly sporadic removal efficiency occurred following this and was further complicated by chlorinator operational problems.

Thus, this run at a high flow rate did demonstrate a quantifiable reduction of arsenic for a throughput of 55 m^3 but it was not as high a removal efficiency as at the lower flow rate of the first run. The rate of flow appears to have been too high to realistically predict normal home water supply flow conditions and expected arsenic removal efficiencies.

However, both runs at MTC and that one at Home #1 do illustrate a couple of points about arsenic removal treatment on "low" arsenic sources. The first aspect is that the raw water in these cases had arsenic greater than the Objective Criterion, but less than the Rejection Criterion. As earlier indicated, one of the purposes at the beginning of this study was to test an arsenic removal unit to determine if it could provide treated water to meet the Objective Criterion since the raw water already is within the Rejection Criterion.

In this study of the N.S.R.F.C. system, arsenic removal to meet the Objective Criterion was possible for the initial throughput using fresh filter media. The volume appears to vary with the initial arsenic concentration to be removed, the flow rate and possibly with general water chemistry. By limiting the volume of water to be treated, such as by treating only drinking and cooking water, the device is capable of providing treated water which will meet the Objective Criterion for an extended period of time (see Table 4).

Filter media changes require a maintenance call and the purchase of new media which could be considered an expensive operation if required more than once per year. Filter media changes at intervals of longer than one year are considered insufficiently routine for the homeowner to remember. Furthermore, since breakdown of arsenic removal is only evident through laboratory analysis results reported many weeks after the time of sampling, annual replacement will provide an enhanced safety factor, and is recommended.

The second point that this study showed was that the arsenic levels of "low" arsenic sources, (Avg. ~15 µg/L) while fluctuating constantly, did not exceed the Rejection Criterion at any time. Long term sampling of other "low" level arsenic sources (<25 µg/L) in the area showed similar characteristics.

Hence, while an arsenic reduction unit can provide a benefit by reducing arsenic levels, none of the sources sampled averaging 25 µg/L or less ever exceeded the Rejection limit. The cost/benefit of providing treated water for the sole purpose of meeting the Objective Criterion for arsenic, when water is considered potable if arsenic is consistently below the Rejection Criterion, becomes debatable.

While this study was in progress, the Northeastern Region of the Ministry decided that individual water sources having an average concentration of 25 µg/L arsenic, or less, can safely be used for consumptive purposes without need for arsenic reduction treatment. Sources having an average arsenic concentration greater than 25 µg/L are considered to have the potential to exceed the Rejection Criterion for arsenic and are not recommended as potable water sources without arsenic reduction treatment.

(b) High Arsenic Levels

At Home #2, an arsenic reduction system was installed to investigate treatment performance at high arsenic levels (136 µg/L avg.). Figure 6 depicts the performance of the unit at this site.

Levels of arsenic ranged from 50 µg/L to 280 µg/L. In spite of these levels, the unit produced a treated water which met the Objective Criterion for the initial throughput of 5.7 m^3.

A total of 64.8 m^3 were treated, of which 47.2 m^3 were produced at an average arsenic concentration of 20.3 µg/L. Four excursions where water quality degraded above the 50 µg/L Rejection Criterion accounted for the remaining volume of water treated and was not included in the computation of the average concentrations of arsenic in the finished water just quoted. Discussion of those excursions follows later.

The N.S.R.F.C. process appeared well-suited for treatment of the higher level of arsenic. Excluding the excursions, a consistent removal efficiency with the treated water being below the Rejection Criteria occurred up to the end of the experiment. Unfortunately, extension of the experiment to determine the total life of the media to reduce arsenic below the Rejection Criterion was not possible.

A calculation of the arsenic removal capability of the filter media with respect to the raw water arsenic (Lutwick, 1979) would suggest that a filter life of 516 days could be anticipated. Hence, annual filter

replacement would appear sufficient to produce water that meets the Rejection Criterion. Review of the performance of N.S.R.F.C. units in operation near Dartmouth, Nova Scotia on private groundwater supplies of similar raw water arsenic levels also indicates that a treated water with less arsenic than the Rejection Criterion was provided for periods longer than one year. All household water was treated in those studies.

Only on four occasions did arsenic of treated waters exceed the 50 µg/L Rejection Criterion and only once did treated levels exceed that of the raw water.

The first occasion of higher arsenic in treated waters resulted from the sampling of one of the short term occurrences of rusty-brown, cloudy water received at the kitchen tap. The sample was found to contain a substantial amount of arsenic and iron.

The second occurrence of elevated arsenic in treated waters resulted from incomplete chlorination of raw water because the hypochlorite solution tank was allowed to go dry. Hence, oxidation of Arsenic (III) to Arsenic (V) did not occur. Since the units remove Arsenic (V) more efficiently than Arsenic (III), the non-oxidized Arsenic (III) was not removed. A

speciation analysis of the raw water indicated that Arsenic (III) makes up approximately 30% of the total arsenic in the well water at this site, thus accounting for the higher total arsenic levels in the treated water on this occasion. Significant loss of arsenic removal efficiency was also noted during the 2nd run at the M.T.C. garage due to problems in maintaining a chlorine residual. The presence of a chlorine residual is necessary to demonstrate to the operator that complete oxidation of Arsenic (III) to Arsenic (V) is occurring.

The third and fourth occasions of elevated arsenic levels occurred during the operation of a water softening unit installed to remove iron prior to treatment by the arsenic unit. When the laboratory analysis revealed the lower efficiency of arsenic removal, the water softener was taken off-line. Arsenic removal by the arsenic reduction unit returned to its former level of acceptable performance. When the water softener was put back on line, the loss in arsenic removal returned. This is indicated by the last sample taken at 65 m^3 shown in Figure 6.

The water softening unit was installed late in the study as a remedy to the frequent occurrences of rusty-brown water which caused discoloration to toilet bowls, tanks and washing machines and was therefore undesirable. These incidents occurred only for short periods of time (less than one minute while the tap was on) then cleared.

This phenomenon was thought to occur due to the naturally elevated levels of iron which became oxidized by the addition of hypochlorite to the water supply. The reaction continued with the formation of iron hydroxide floc which was retained by the filter bed until it was flushed out by periods of high water usage.

The iron hydroxide accummulation in the arsenic reduction filter unit may also provide a medium for the proliferation of iron-reducing bacteria. These bacteria are not harmful if consumed by humans. However, they may cause occclusions of the interstitial pores of the filter media, and possibly, due to bacterial activity promote chemical reducing conditions, causing resolubilization of the previously precipitated arsenic.

To investigate the potential for loss of arsenic removal efficiency due to iron bacterial activity, the arsenic reduction unit at Home #2 was taken out of service, drained, refilled with strong hypochlorite solution, and allowed to stand for 24 hours. After this time, the unit was put back into service and the water system flushed. As a further anti-bacterial measure, iodine was added to the hypochlorite solution

supply to provide a concentration of 100 µg/L in the water entering the arsenic removal filter media. However, during the following two week period, no measurable improvement in the arsenic reduction ability of the unit was observed.

It was further theorized that iron removal before oxidation might best be considered to prevent the build up of iron in the arsenic removal filter bed. It was at this time that the water softening unit was installed. The object of this measure was to improve arsenic reduction performance while solving the "brown water" problem.

Upon installation and operation of the water softening unit in Home #2, the "brown water" occurrences ceased, water hardness was reduced (187 to 20 mg/L $CaCO_3$) and sodium levels increased (34.8 to 128 mg/L Na). The unpredicted reaction, however, was a severe decrease in the efficiency of the arsenic reduction unit. It was during this period that arsenic levels in treated water exceeded raw water and rose to concentrations as high as 100 µg/L.

Lutwick (1979) in his studies in Nova Scotia also had arsenic reduction units installed in homes with high iron levels in their water and iron removal units

previously installed on their water supplies. Arsenic reduction efficiencies were apparently not affected in these cases.

When analysis results revealed the increase in arsenic in the treated water, the water softening unit was taken off-line and the arsenic reduction unit returned to its former level of arsenic removal efficiency. Since the water softener was installed near the end of the study, there was insufficient time to determine the cause of the breakdown of the arsenic reduction unit during operation of the water softener.

The reasons for reduced performance of the arsenic unit when preceded by a sodium-based ion exchange type water softener are not fully understood at this time. It is possible however, that the resultant soft water, low in calcium but high in bicarbonate ions, could be a more aggressive chelating agent toward iron, since both iron and calcium are molecularly similar. This aggressiveness would be more pronounced with iron hydroxides newly formed through the oxidation of iron in the raw water by the added hypochlorite which occurred at this site. If the fresh hydroxide floc was associated with arsenates, some of the iron and arsenic could possibly be resolubilized. Thus, some could leave the filter media, and give increased levels of arsenic in the finished water.

A sodium-based ion exchange type water softener was selected because of its immediate availability to demonstrate that iron removal in tandem with an arsenic reduction system could produce an aesthetically acceptable water for high iron supplies. For actual drinking water usage, it would be prefereable to use an alternative iron removal process which did not significantly increase the sodium concentration in the treated water.

Use of a potassium permanganate ("green sand") type iron-removal filter would be more appropriate. This iron-removal process would not increase sodium levels. If located downstream of the arsenic reduction system, no effects on arsenic removal efficiencies would be anticipated.

In summary, the N.S.R.F.C. arsenic reduction system worked very well at removing arsenic from a raw water with levels of arsenic greatly exceeding the Rejection Criterion. The reduction system consistently produced a treated water which did not exceed the Criterion.

Actual breakthrough of the filter did not occur over the 5 months of the experiment. The N.S.R.F.C. system would appear to be capable of treating all household

water at this incoming arsenic concentration to meet the Rejection Criterion with only an annual filter media replacement. However, due to the curtailment of the operation of the unit at Home #2 after only 144 days, a full year's performance was not proven in this study.

Groundwater characteristics, such as excessive iron or turbidity appeared to be responsible for a reduction in the effective operation and life of the filter media at Home #1. Reduction of filter media life results in the need for more frequent filter media replacement. Due to iron problems at Home #2, a reduction in filter media life is anticipated to occur at this site also.

Longer filter media life and an enhanced safety factor of treatment can be provided by limiting arsenic reduction treatment to drinking and cooking water only. Such a measure would extend the theoretical life of the media to 2.5 years. However, a filter media replacement routine for periods longer than one year does not seem reasonable for a process that relies on laboratory analysis results received after the fact to indicate that the process is operating.

With respect to water supplies with high levels of iron, aesthetic problems (i.e. periodic "brown water" clouds) may occur due to the chlorination required for

the arsenic reduction system. Use of an iron-removal system in conjunction with the arsenic reduction process is recommended to eliminate these problems. Location of the iron removal unit upstream of the arsenic reduction system (the preferred location to prevent iron buildups in the arsenic reduction filter) may cause loss of arsenic removal efficiency and should be investigated at the time of implementation. Relocation of the iron-removal unit to downstream of the arsenic reduction system may be necessary.

2. Optimizing Efficiencies by Chemical Additions

As determined in previous laboratory studies (Lutwick 1980), arsenic removal occurs most efficiently within a pH range of 4 to 8, and increased arsenic removal should occur towards the lower end of that range. In an effort to optimize the arsenic removal efficiency of the units which were operated on waters of pH range 7.5 to 7.9, and at low arsenic levels, consideration was given to pH control.

A short duration acid addition experiment was carried out at Home #1 by the installation of an additional solution tank and chemical feed pump also designed to come on with the well pump for the purpose of injecting a pH reduction solution (i.e. acid). During the tests, which were carried out between 61 and 79 m^3 of water throughput (see Figure 3), field pH measurements were taken and adjustments were made to the acid solution feed pump to attain the desired pH in the treated water. Initially, the pH was reduced from an average of 7.3 to 6.5. Later, in the last week of the experiment, the pH was depressed from 7.3 to 5.5. by adjustment of the chemical feed pump and the solution strength.

No substantial reduction in arsenic concentrations was found after pH adjustments vs. before acidification (see Table 5). Indeed, incidents where arsenic in treated water exceeded raw waters continued during this period. Unfortunately, the length of time available for this experiment was insufficient to determine whether pH control would prolong the effective lifetime of the arsenic reduction filter media or why the experiment did not produce enhanced arsenic removal.

The improvement in arsenic exchange efficiencies at lower pH should theoretically take place. It reduces hydroxyl ion concentrations which favors arsenate ions in the competition of arsenates and hydroxyl ions for available iron.

A pH decrease however also favors conditions of chemical reduction including the reduction of Fe^{+3} species to Fe^{+2} species. This chemical reduction would allow solubilization of iron, and, if iron species are associated with arsenic, both ions could leave the filter media. This could occur even though oxidants are added to the raw water, especially if, as in the case of Home #1, H_2S is in sufficient concentration to reduce the effectivenss of the added oxidants.

3. Operating Reliability and Maintenance

Table 6 summarizes the operating periods of each unit in terms of days of service and volumes processed. During the combined period of operation, a total of 350.5 m^3 (76,908 gallons) of water was treated by the arsenic reduction units.

Although new to both operators and installers, the units did not pose major problems and little maintenance was required. In the total 564 days of operation, the units were considered inoperative for only 20 days, or 3.5% of the time.

The causes of this "down time" were not directly related to the exchange units themselves. The fouling of one chemical feed pump for the hypochlorite solution and the fact that the solution reservoir was allowed to run dry for short periods of time accounted for most of the "down time". The remaining incident was due to the improper installation of an in-line carbon filter. This problem was quickly noticed by a drop in water pressure and subsequently corrected.

All operation of the arsenic reduction systems was performed by Ministry staff when making their routine visits for sampling. When mechanical problems were

recognized or major maintenance required (i.e. change of filter media, maintenance of chemical feed pump), a representative of the equipment installation firm was brought in to perform the work.

The homeowners of the two residences where the systems were installed were not involved in the operation of systems.

The homeowners did express some concern about having to operate these systems on their own. However, it is believed that most problems that might occur have been determined and corrected through the field trials of this study and by the following operating methods.

1. Checking the hypochlorite solution reservoir (tank) on a weekly basis to ensure that an adequate quantity is available for the following week. If low, additional hypochlorite (domestic javelle water) and distilled water would be added in the specified ratio to top up the tank. Use of raw well water may result in clogging of the chlorinator.

2. Checking the chlorine residual from the pressure tank outlet tap on a weekly basis to ensure that some residual is present (0.25 to 0.50). This involves a simple test with a colourmetric comparator such as that distributed by Wallace and Tiernan Company or Tintometer Limited, among others.

If the residual is found not to be within the recommended range, the solution pumps can be adjusted to achieve this.

3. Taking samples of water for arsenic analysis from the raw water tap and the drinking water tap once per week during the first month of operation, and every 3 months (quarterly) thereafter.

4. Replacing arsenic reduction system filter media on at least an annual basis.

5. Following the manufacturer's procedures for operation and maintenance of the chlorination units.

4. Capital and Operating Costs

The costs experienced for the purchase, installation and operation of two arsenic-removal systems to perform this study were used to project those costs which could be anticipated for private installation.

The capital costs to set up two arsenic removal systems in November, 1980 are shown in Table 7. These costs have been reviewed with the original supplier in November, 1981 to determine the likely costs in 1982. An anticipated installed capital cost is $1,795./unit.

Operating costs for the basic arsenic removal units are broken down in Table 8 and show an annual operating cost of $275.00. This cost includes the annual replacement of the arsenic removal filter media by a servicing technician.

For the Chelmsford field trials, the arsenic reduction units were installed to treat all household water. However, depending on the required degree of treatment (whether to Objective or Rejection Criterion) replacement of the filter media more than once per year may be required. Because the costs for reinstallation of new filter media is projected to be $225.00, it would appear more reasonable to try to limit replacement of filter media to once annually.

If more frequent replacements appear necessary, then it would be reasonable to treat only that water used for drinking and cooking instead of all household waters. Hence, an arsenic removal filter installed to serve, for example, the kitchen tap only, would require only annual filter media replacement and would still provide a wide margin for safety. Costs to revise the plumbing to treat drinking water only would be specific to each house and no estimate has been included for this additional piping.

Where the raw water supply has high iron, problems of "brown water" clouds may occur. In this situation, an iron removal unit may also have to be installed to overcome the aesthetic problems created by the chlorination required for the arsenic reduction system.

The capital cost breakdown for installation of a potassium permanganate unit for iron removal is shown in Table 7 and is projected to cost $625. in 1982. A breakdown of the estimated operating costs of a unit is shown in Table 8 and totals $40.00/year.

Thus, the total projected cost to install a basic arsenic reduction unit is approximately $1,795. with an operating cost of $275./year. If iron removal is also needed, the total capital costs with arsenic removal units would be $2,420. and operating expenses of $315.00/year. If piping for provision of a treated drinking water tap is necessary, it would be additional to these estimates.

CONCLUSIONS

1. The basic conclusion of this study is that the arsenic removal system developed by the Nova Scotia Research Foundation Corporation (N.S.R.F.C.) does reduce arsenic found in groundwater of some Chelmsford area wells.

2. The arsenic reduction system can provide treatment to meet the Objective Criterion for arsenic for a limited throughput volume.

3. The arsenic reduction system appears well suited to remove sufficient arsenic to ensure compliance with the Rejection Criterion, even with raw water arsenic concentrations ranging up to 5 times that value.

4. In view of the water quality in the Chelmsford area, treatment of all household water may require several filter changes in order to assure meeting the Rejection Criterion. If only drinking and cooking water is treated, the required water quality is assured for a period of in excess of one year with only annual filter media replacement.

5. Excessive levels of iron in raw water appear to adversely affect the operation and the aesthetic acceptability of the arsenic reduction systems but can be rectified by including iron removal within the system.

6. The pH control experiment did not show appreciable improvement in arsenic removal efficiency and was inconclusive with regard to its effects on the prolongation of the lifetime of the filter media.

7. Capital and operating costs were determined to be: $1795. and $275./year for a simple unit. If further water quality improvements are necessary (iron removal) in addition to the arsenic reduction system, the costs would be greater than the above.

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Table Number	Title
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3	Arsenic Reduction Unit Efficiencies
4	Estimates of Prorated Lifetime of Arsenic Reduction Units
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TABLE 1 - CHRONOLOGY OF FIELD TESTS OF ARSENIC UNITS

Testing Site	Date of Receipt of Media	Date Installed	Date Last Sample Taken
Home #1	Aug. 28/80	Nov. 14/80	June 3/81
Home #2	Apr. 14/81*	Apr. 24/81	Sept. 15/81
MTC #1	Aug. 28/80	Nov. 5/80	Apr. 22/81
MTC #2	Apr. 14/81*	July 14/81	Sept. 11/81

*Submerged in water during storage.

TABLE 2 - SUMMARY OF AVERAGE GENERAL WATER QUALITY

Parameters	Home #1		Home #2		M.T.C. (Runs 1 & 2 Combined)	
	Raw	Treated	Raw	Treated	Raw	Treated
pH	7.5	7.4	7.8	7.9	7.8	7.9
alkalinity (as $CaCO_3$)	250	250	256	264	299	300
conductivity (umhos/cm)	553	553	489	515	954	965
hardness (as $CaCO_3$)	284	288.1	186	187	421	424
Turbidity (F.T.U.)	19.7	2.69	5.0	0.28	1.07	0.87
Sodium	16.5	19.2	34.8	38.2	48.6	48.5
Magnesium	28.9	28.6	17.0	17.0	-	-
Sulphate	58.4	57.4	3.4	3.7	28.7	28.8
Chloride	4.6	6.5	2.9	18.6	140	142
Fluoride	0.20	0.20	0.34	0.33	0.25	0.24
Nitrates	0.10	0.10	0.16	<0.10	0.60	0.65
Iron	1.79	1.26	1.33	0.40	0.069	.047
Copper	0.038	0.066	0.007	0.076	0.077	.072
Manganese	0.42	0.44	0.196	0.002	0.082	.078

All results expressed in mg/L, except where indicated.

TABLE 3 - ARSENIC REDUCTION UNIT EFFICIENCIES

Testing Site	Mean As Conc. Raw (µg/L)	Mean As Conc. Treated (µg/L)	Volume Treated to <10 µg/L (m^3)	Total Volume Treated (m^3)
Home #1	14.6 (6.0)	8.5 (7.0)	33.2	82.6
Home #2	136.4 (48.2)	20.7* (15.7)	5.7	47.2*
MTC				
Run #1	15.6 (5.8)	11.7 (5.0)	38.1	102.6
Run #2	25.0 (7.8)	17.4 (11.6)	3.9	118.1

* Data from the period of operation of the water softener not included.

() Figures in parenthesis refer to one standard deviation.

TABLE 4 - ESTIMATES OF PRORATED LIFETIME OF ARSENIC REDUCTION UNITS

Site	Volume Processed to 10 µg/L (m^3)	Prorated life Expectancy (days) at 0.05 m^3/day Consumption	Total Processed Volume with Less Than 50 µg/L (m^3)	Prorated life Expectancy (days) at 0.05 m^3/day Consumption
Home #1	32.3	646	82.6	Not Applicable
Home #2	5.7	114	*47.2	*944
MTC				
Run #1	38.1	762	102.6	Not Applicable
Run #2	3.9	78	118.1	Not Applicable

*This refers to the volume of water treated up to but not including the period of operation of the water softener. This figure is thus an underestimate of the total volume treated during the study.

TABLE 5 - pH ADJUSTMENT EXPERIMENT AT HOME #1

	pH		Arsenic Concentrations (µg/L)			
	During Experiment		Before pH Expt.		During pH Expt.	
	Raw	Treated	Raw	Treated	Raw	Treated
mean	7.3	6.5	14.2	8.2	15.9	8.7
standard deviation	0.1	0.2	8.0	6.6	4.1	8.1

TABLE 6 - SUMMARY OF ARSENIC REDUCTION UNIT OPERATION AND DOWN TIME

Site	Days in Service	Days out of Service	Total Volume Processed (m^3)	Comments
Home #1	200	4	87.6	Improper installation of in-line carbon filter
Home #2	144	6	47.2	Chlorine solution ran out
MTC #1	168	0	102.6	
MTC #2	52	10	118.1	Chlorinator failure
Total	564	20	350.5	

One m^3 = 1,000 litres
≅ 220 gallons

TABLE 7 - SUMMARY OF ACTUAL AND ANTICIPATED CAPITAL COSTS

COMPONENTS	ACTUAL COST ($) UNIT 1	UNIT 2	PROJECTED 1982 COSTS ($)
N.S.R.F.C. Filter media	No Cost	No Cost	*150.00
1 hypochlorinator and solution tank	246.00	246.00	400.00
1 25 x 122 cm fiber-glass tank with internal piping	225.00	225.00	260.00
Miscellaneous Materials			
Activated carbon filter and cartridge, 1.25 cm water meter, 1.25 cm shutoff valve, sampling taps, air release valve, required copper piping	225.00	225.00	290.00
Colourmetric Chlorine Residual Comparator			250.00
Labour	472.00	351.00	445.00
TOTAL	1,168.00	1,047.00	1,795.00
With Iron Removal Unit	--	(a) 640.00 1,687.00	(b) 625.00 2,420.00

*Estimated cost only, commercial preparation is presently under consideration and costs have as yet been undetermined.

(a) Water Softening Unit.

(b) Iron Removal Unit Only.

TABLE 8 - YEARLY OPERATING COSTS OF ARSENIC REDUCTION SYSTEM

Maintenance Items	Costs ($)
New N.S.R.F.C. Filter Bed	* 150.00
Shipping and Installation	75.00
General Repair, Maintenance Javelle Water	50.00
TOTAL	275.00
Iron Removal Unit	40.00
Total Operating Costs (Iron Removal Unit Included)	315.00

*Estimated Cost Only (See Table 7).

APPENDIX:

LIST OF COMPONENTS COMPRISING THE ARSENIC REDUCTION SYSTEM.

1 25 x 122cm Fiberglass Tank with Internal ½" piping and cap by Structural Fibers Inc.

1 N.S.R.F.C. Filter Media (0.03 m^3)

1 1.25cm Air Release Valve

1 Chemical Feed Pump,
Amco Arizona Minerals
Model AC-7
Or
Model AC-22

1 In-line Activated Carbon Filter
Envirogard Products Limited

1 1.25cm Water Meter
Various 1.25cm Copper Sampling Taps and Shutoff Valves.

1 Aquafine Water Refiner ATE 220 with Brine tank.

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6	Arsenic Concentrations vs Water Consumption for Home #2

FIGURE 1

MAP SHOWING STUDY AREA

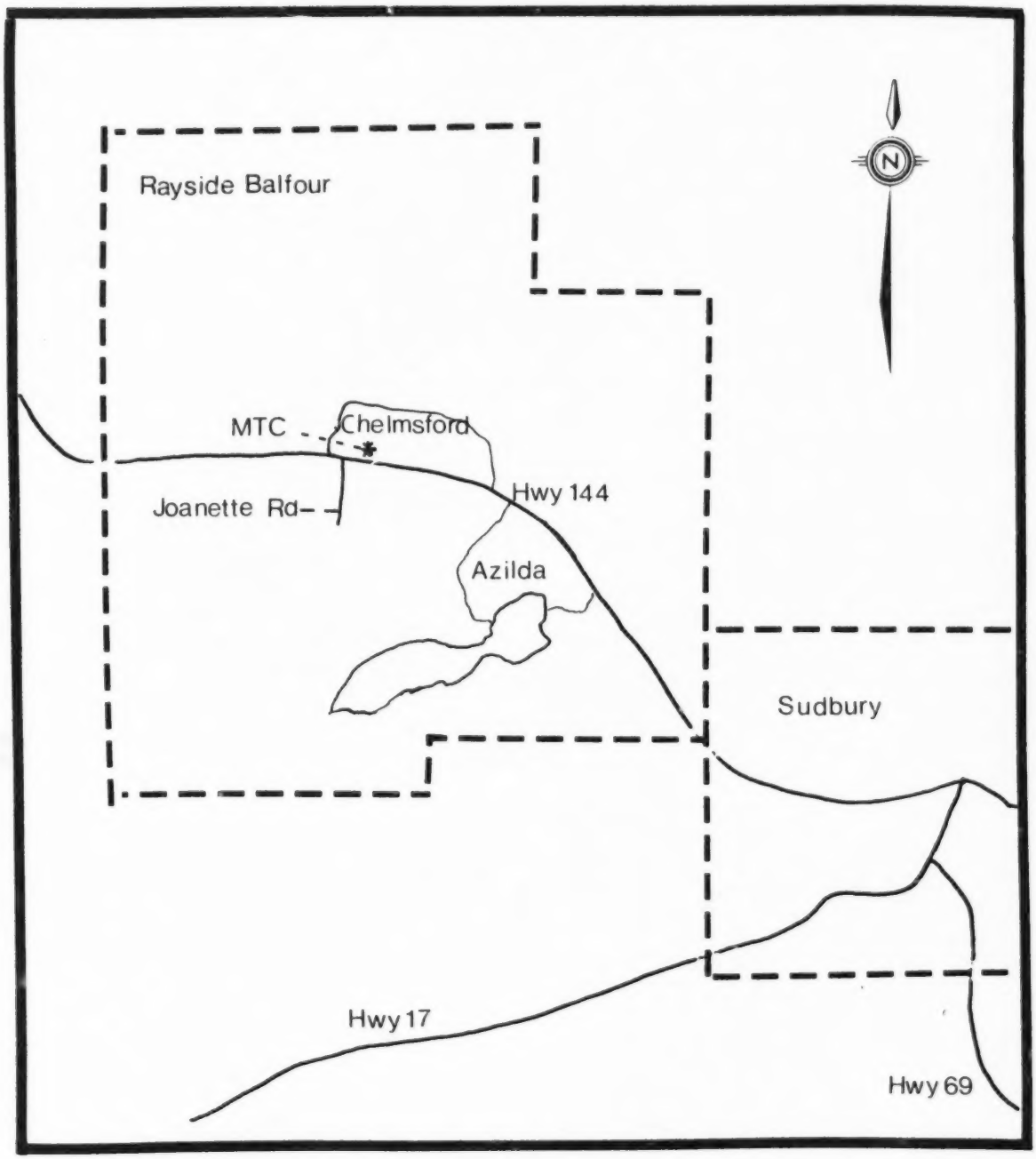


FIGURE 2 - SCHEMATIC DIAGRAM OF ARSENIC EXCHANGE UNIT

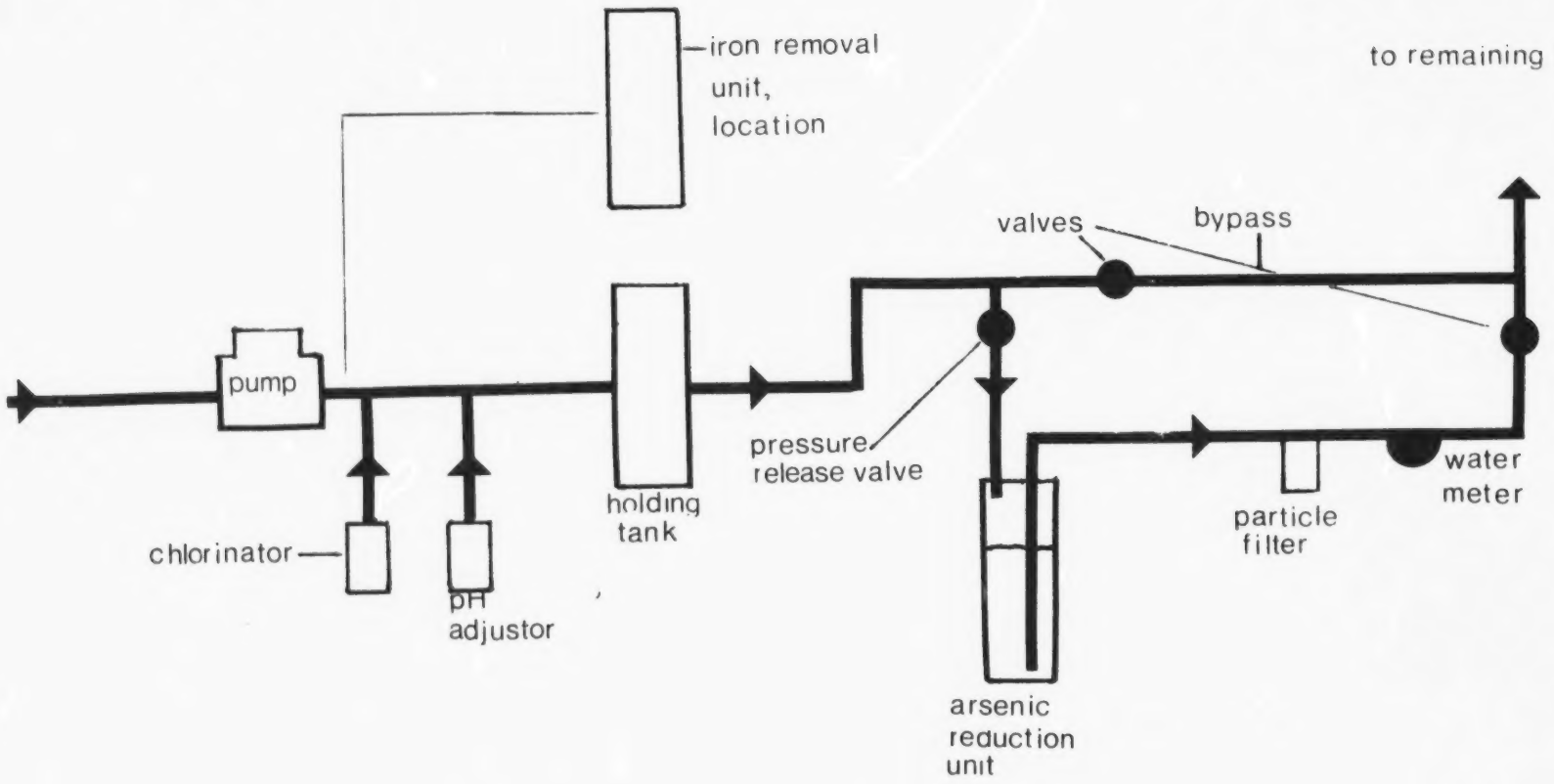


FIGURE 2

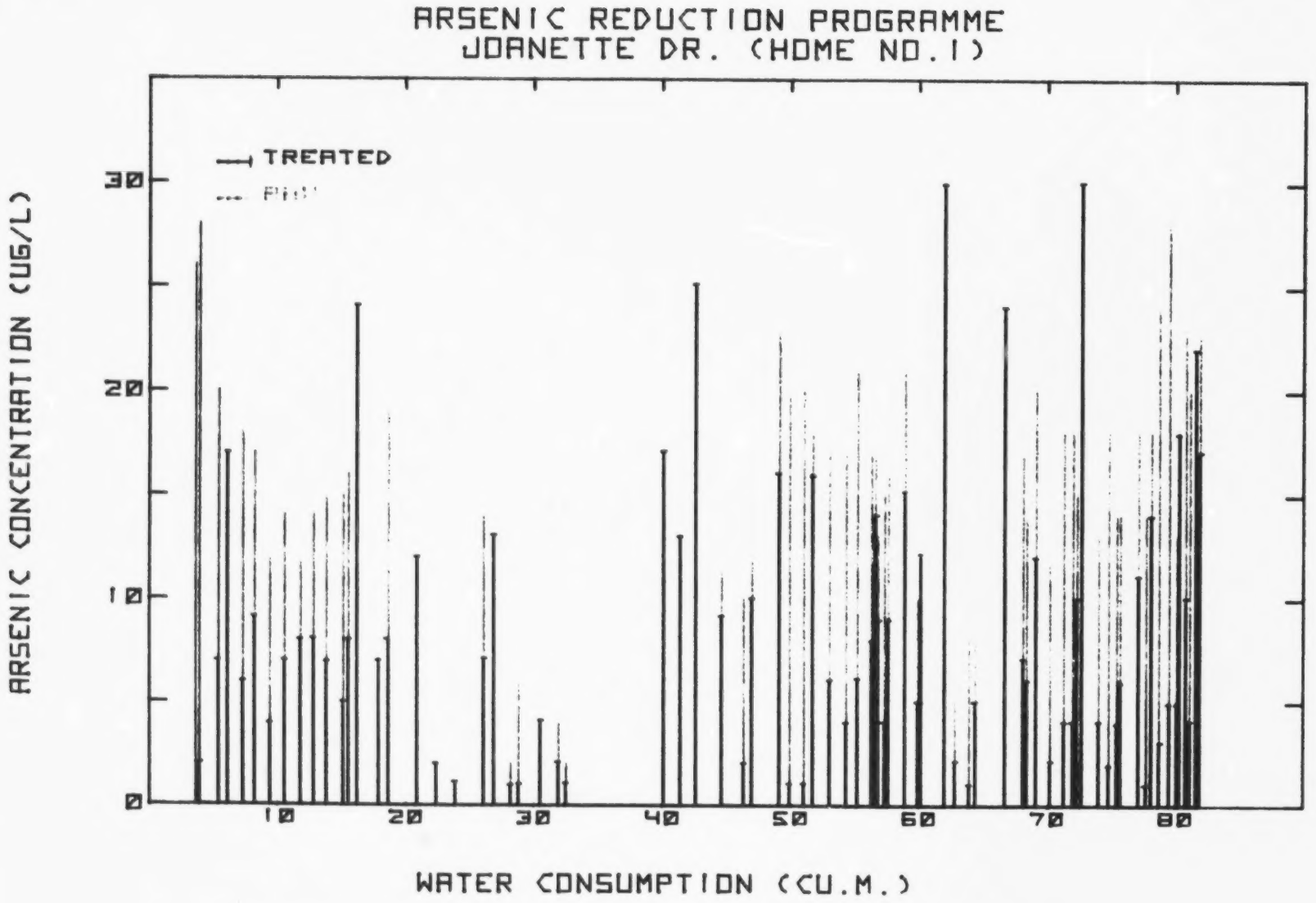


FIGURE 3

FIG.3 PERIOD: NOV.20/80 TO JUNE 3/81

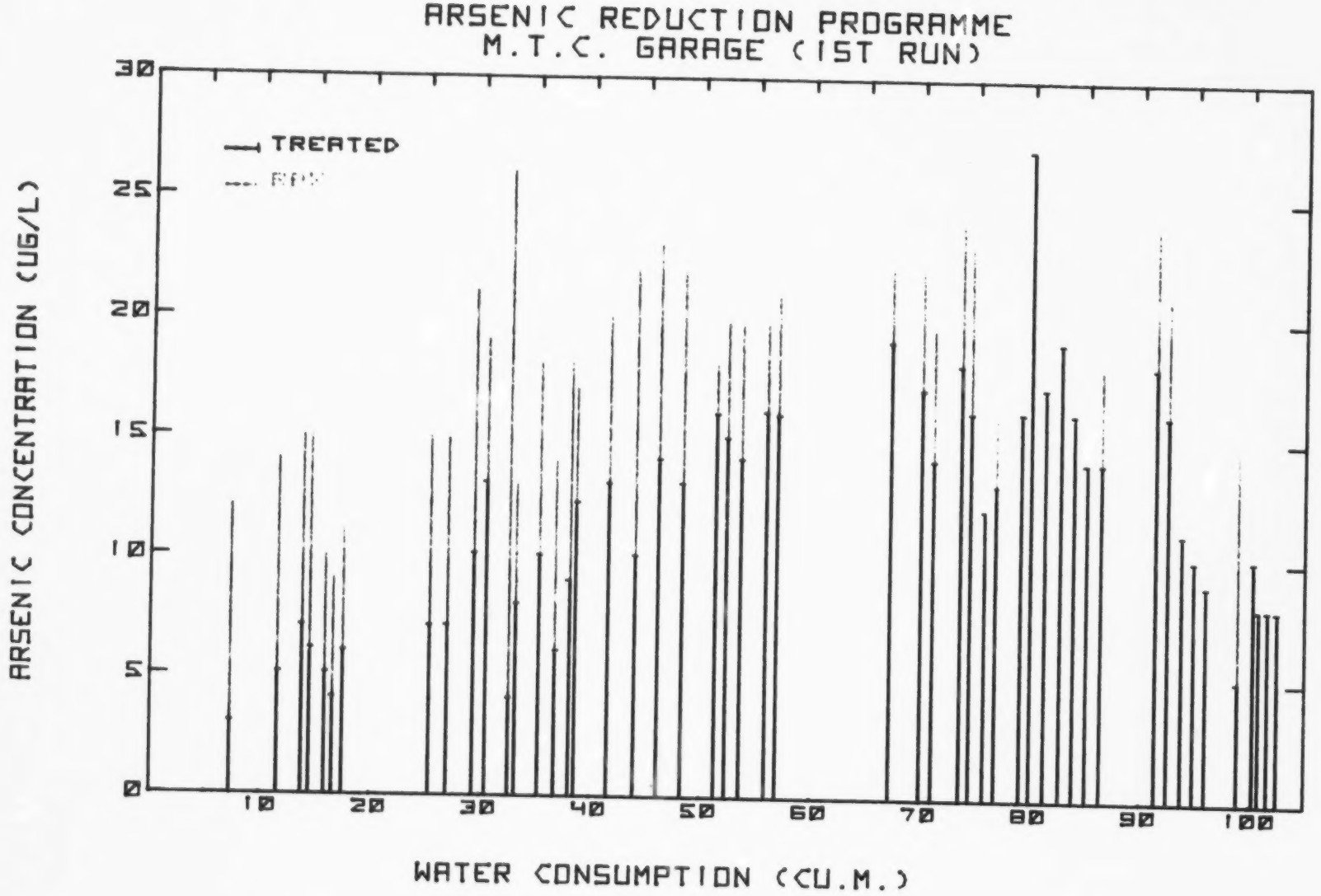
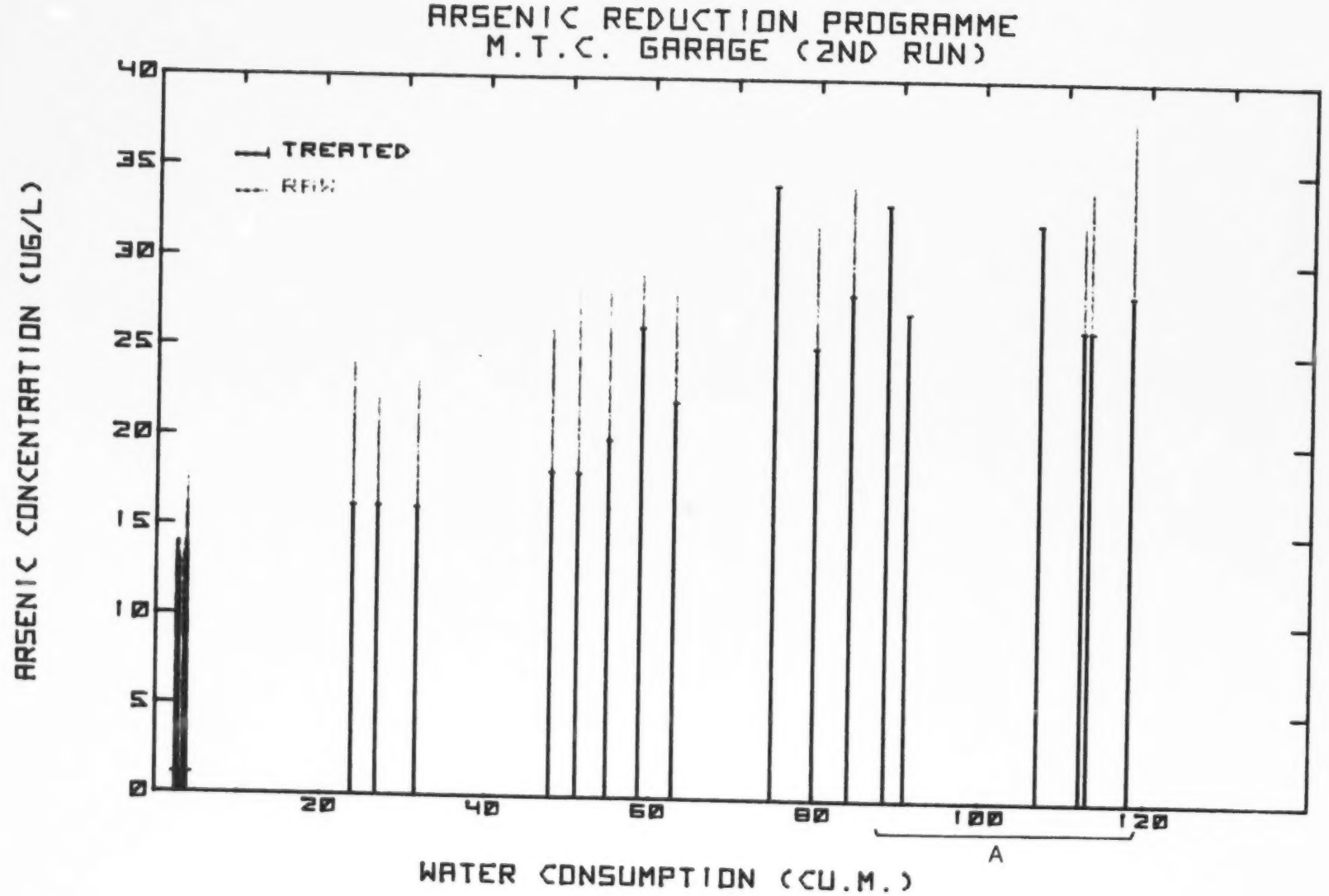


FIGURE 4

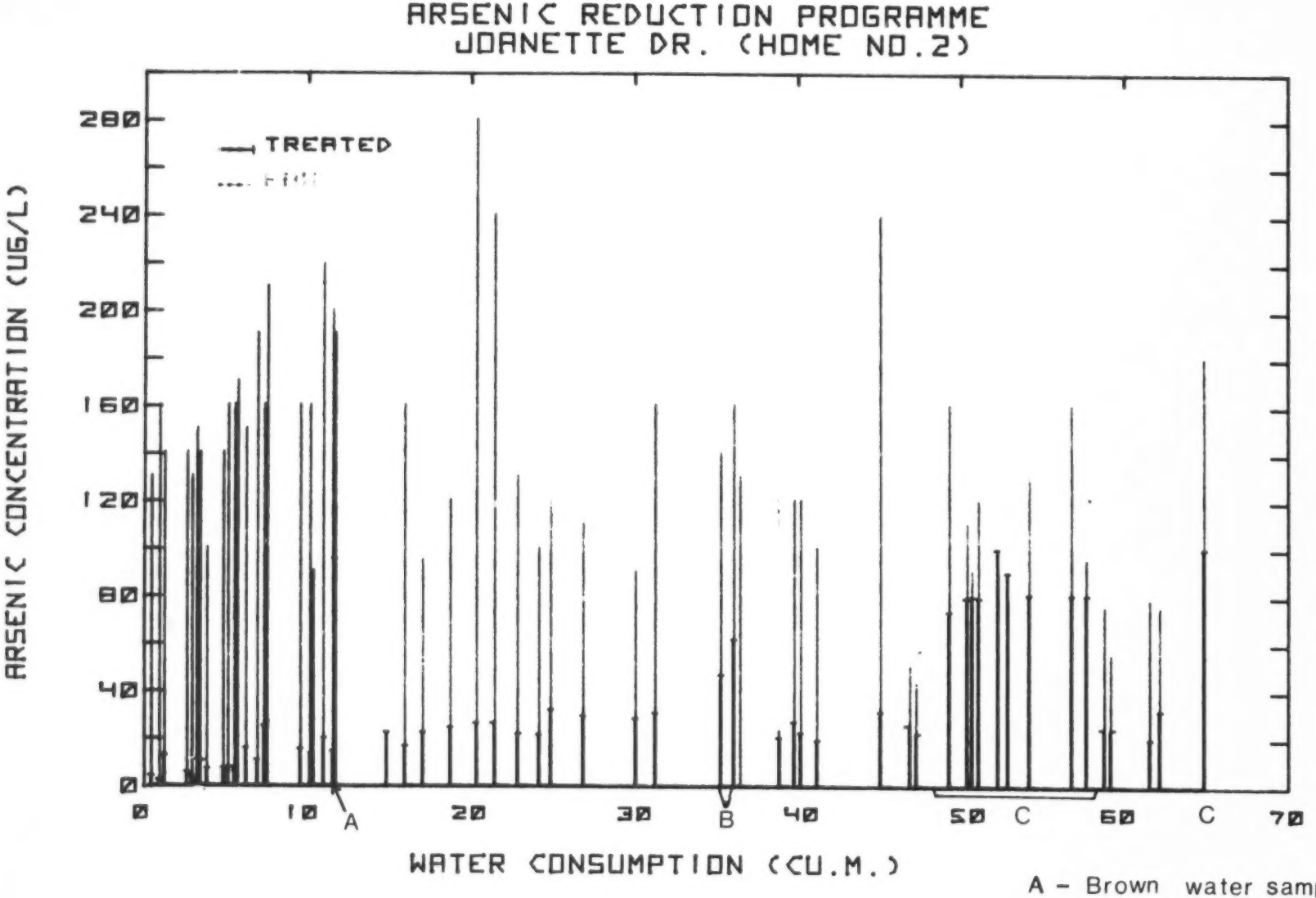
FIG.4 PERIOD: NOV.14/80 TO APR.22/81



A - Refers to period of operation when chlorinator was not functioning.

FIGURE 5

FIG.5 PERIOD: JULY 20/81 TO SEP.4/81



A – Brown water sample.
B – Refers to period when hypochlorite solution ran dry.
C – Period of operation of the water softening unit.

FIG.6 PERIOD: APR.28/81 TO SEP.15/81

FIGURE 6

POOR

QUALITY

ORIGINAL